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Investigations of Coal Purification by Selective Oil Agglomeration

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ABSTRACT

Selective oil agglomeration is used as a physical method to reduce impurities in coal fines. The efficiency of the process depends on many factors. The effects of many operating variables have been examined for different coals and tailings, and the efficiency of the process in coal cleaning has been demonstrated. This study summarizes the work carried out in order to develop coal oil agglomeration as a technique for a cleaner coal-water-fuel slurry production.

INTRODUCTION

One of the problems of coal utilization as a combustible is the presence of mineral matter which increases the impurities in the atmosphere and can cause important corrosion or erosion problems in boiler installations. Filter utilization is expensive and increases the cost of the process. In this study, selective oil agglomeration is used as a simple physical technique to reduce impurities in coal before its introduction in boilers as a coal-oil-water slurry (1–4).

Many studies have already been carried out to apply this method to coal (2–7). In this study, the work realized in our laboratory is summarized in order to study the effects of different variables, to test the efficiency of the method, and to choose optimum factor values for slurry production in a pilot plant.

The selective oil agglomeration process is a solid/solid separation method. The treatment of coal fines in aqueous suspension consists of separating the carbonaceous fraction from the ash-forming mineral matter. The separation process based on oil agglomeration involves the principle of preferential wetting of hydrophobic carbonaceous particles by oils (hydrophobic). This selectivity allows the coal (carbonaceous matter) to be wetted by oil, and the impurities (minerals, trace metals), which are typically hydrophilic, to remain in aqueous suspension. In the presence of an adequate amount of oil and sufficient mechanical agitation, the oil-coated coal particles collide with each other and form agglomerates of sufficient size to permit separation with the help of a sieve and then recovery.

Agglomerate growth depends on many process variables and affects the deashing and the recovery efficiency of coal as well as its moisture content. The following phenomena may affect the agglomeration process: nature and concentration of oil, nature of coal, coal particle size, concentration and conditioning of coal/water suspension, agitation duration and intensity, pH, temperature.

EXPERIMENTAL

Coal size reduction was carried out with a wet grinder (Netzsch LM-4). Then, suspension of coal fines in water was used for agglomeration study with different oils. A high-speed blender (2 L, diameter 120 mm) agitated by a 6-bladed flat turbine (radius 30 mm, height 10 mm, situated 5 mm from the bottom) was used as a batch reactor for coal-oil agglomeration. Many types of coal, particle sizes, and oils have been tested. Other factors like concentration of coal in water suspension, agitation characteristics, and temperature have been considered.

For each experiment the concentration of coal in water was fixed. After a homogenization period, a quantity of oil was added according to the oil/coal ratio determined for each experiment. After an agglomeration period, the agglomerates-impurities-water system was passed over a given sieve in order to separate impurities and water.

Ash content in agglomerates was determined according to the ASTM D3174 method (8). Coal recovery and moisture were also determined. The moisture was determined with a Dean–Stark distillation (2). Toluene was used as solvent. Coal weight in agglomerates may be determined with a filtration of the sample after elimination of moisture and washing the sample with toluene (2) in order to extract the oil. Coal recovery can be estimated by weighing the initial coal and the coal contained in agglomerates. The rest of the initial sample is the oil content. Particle sizes of coal and agglomerates were measured with a Galai-Laser (Cis-1) particles analyzer.

Each of the operating conditions has been examined in relation to the major objectives of coal preparation, namely: a) reducing the ash content in coal, b) recovery of coal while rejecting impurities, c) reducing the moisture content in the product.

RESULTS AND DISCUSSION

Effect of Nature of Oil

Viscosity and density of oil are very important on agglomeration quality and the efficiency of deashing. The influence of many oils on ash reduction and coal recovery has been studied for Freyming coal with an initial ash content of 6.1% (w/w). Experimental conditions of the agglomeration process are shown in Table 1. These conditions were preserved for the study of the other characteristics each time Freyming coal was examined. The results obtained are given in Table 2.

Coal cleaning decreases with an increase of density and viscosity of oil (Table 2). The chemical family of an oil can affect ash reduction (Fig. 1). Chlorinated hydrocarbons seem to be more effective than saturated aliphatic hydrocarbons which are better than aromatic hydrocarbons. Other authors (5, 9) have also observed this tendency of products derived from aromatics to be less selective than the saturated derivatives. This can be explained by the fact that the character of aromatic hydrocarbons is more hydrophilic and consequently has a higher affinity for minerals contained in coal fines. In fact, interfacial tension is lower for aromatic

TABLE 1
Experimental Conditions for Studying Freyming Coal

Type of coal	Freyming (Fr)
Coal size	0 × 160 μm
Mean size	30 μm
Temperature	20°C
Suspension density	10% coal/water (w/w)
Time of coal wetting	1 minute
pH	7.5
Ratio of oil/coal (wt)	0.05
Agitation period	30 seconds
Agitation speed	2500 rpm
Sieve size	160 μm

TABLE 2
Effect of Oil Nature on Ash Content and Coal Recovery

Type of oil	Density (20°C)	Viscosity (cP), 20°C	Coal recovery (%)	Ash content (%)
1 Pentane	0.63	0.24	65	1.55
2 Petroleum ether	0.65	—	70	1.55
3 Hexane	0.66	0.326	80	1.60
4 Heptane	0.68	0.409	>95	1.62
5 Octane	0.70	0.542	>95	1.65
6 Dodecane	0.75	1.35	>95	1.85
7 Toluene	0.86	0.59	82	2.27
8 Benzene	0.87	0.65	75	2.33
9 Freon 113	0.57	0.68	92	1.55
10 Trichloroethane	1.39	1.2	>95	1.72
11 Fuel oil	0.95	3	>95	2.15
12 Oil of vaseline	0.97	>10	>95	2.6
13 90% fuel and 10% cutback	~1	>15	80	2.9

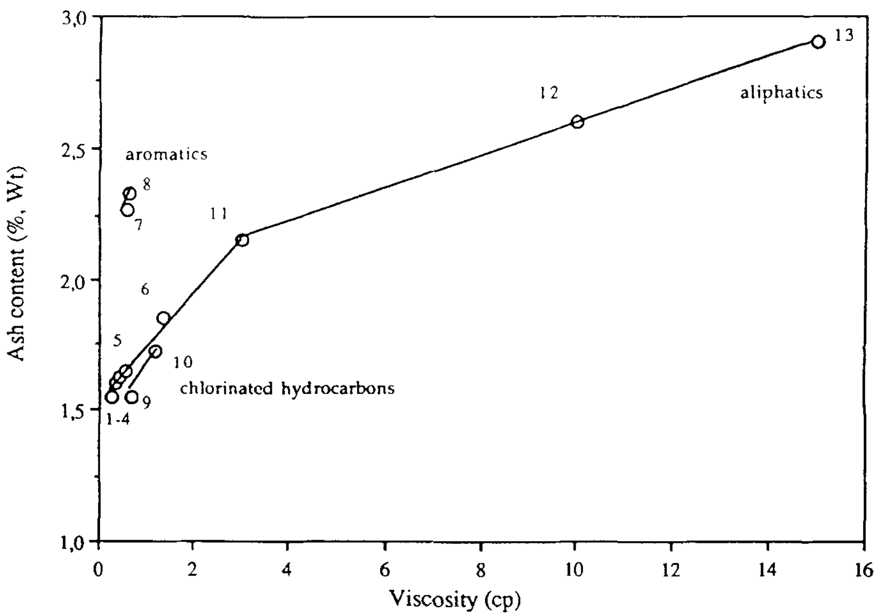

FIG. 1 Ash content as a function of oil viscosity. The numbers refer to the type of oil as listed in Table 2.

than for aliphatic hydrocarbons. It is also observed (Fig. 1) that the increase of carbon range in aliphatic hydrocarbons reduces the efficiency of coal purification.

Coal recovery also depends on oil nature as can be observed in Table 2. A very low or high viscosity oil decreases coal recovery, probably because of lower oil adhesion or dispersion, respectively, during agitation (Fig. 2). There is an optimum range of viscosity (0.6–10 cP) which allows better adhesion of particles with oil and a higher degree of agglomeration. Mazzone et al. (10) showed that under some conditions a continuous deformation of the liquid bridges takes place. In this case, the strength of the bridges (attraction force due to the presence of the liquid) and consequently agglomerate growth depends not only on the shape of the interface but also on the fluid viscosity.

Light fuel oil was used for the next experimental trials, especially because it led to good coal selectivity during agglomeration and a low price for coal-water-fuel slurry production for combustion in boilers.

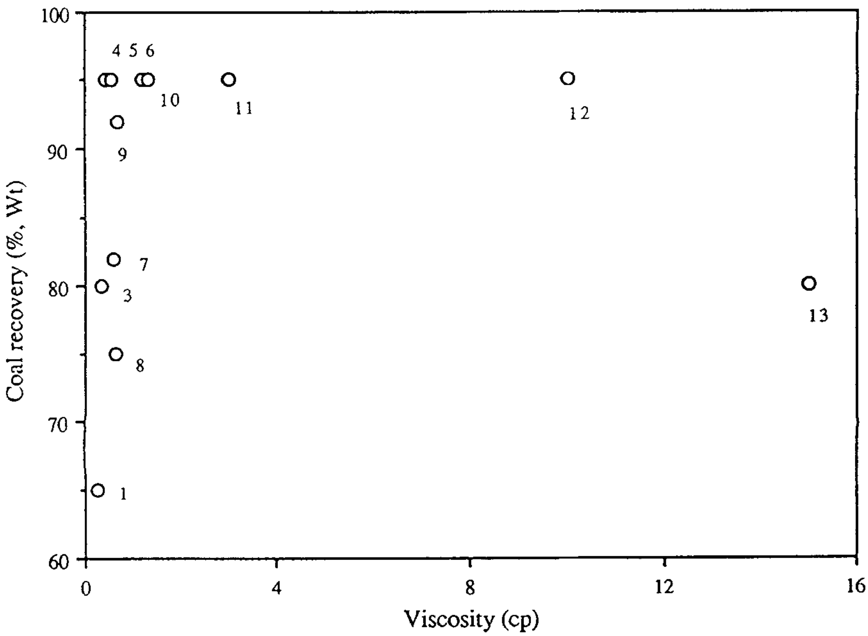

FIG. 2 Coal recovery as a function of oil viscosity. The numbers refer to the type of oil as listed in Table 2.

Effect of Oil Concentration

Oil concentration is a critical factor for agglomerate growth. Both ash reduction and coal recovery are functions of an optimum oil concentration, which makes certain there are significant difference between agglomerate and mineral matter sizes.

The ash content generally decreases with an increase of oil concentration up to an optimum value (Fig. 3). Then agglomerate size becomes very important and may imprison some minerals matters (Fig. 3). The optimum value of deashing for the studied coals is between 0.20 and 0.30 of the light fuel oil/coal ratio. Only French Freyming coal presents an optimum ash reduction for a very low ratio of fuel oil/coal (0.05).

A minimum amount of oil is also necessary for good coal recovery, as it is shown in Fig. 4 for Columbian coal. Some authors (5, 15) have observed that recovery of less hydrophobic coals declined with the addition of excessive amounts of oil, and this was attributed to the formation of a weak coal–oil amalgam that passes through the collecting sieve screen. During the study of oil concentration effect, no decline of coal recovery was observed.

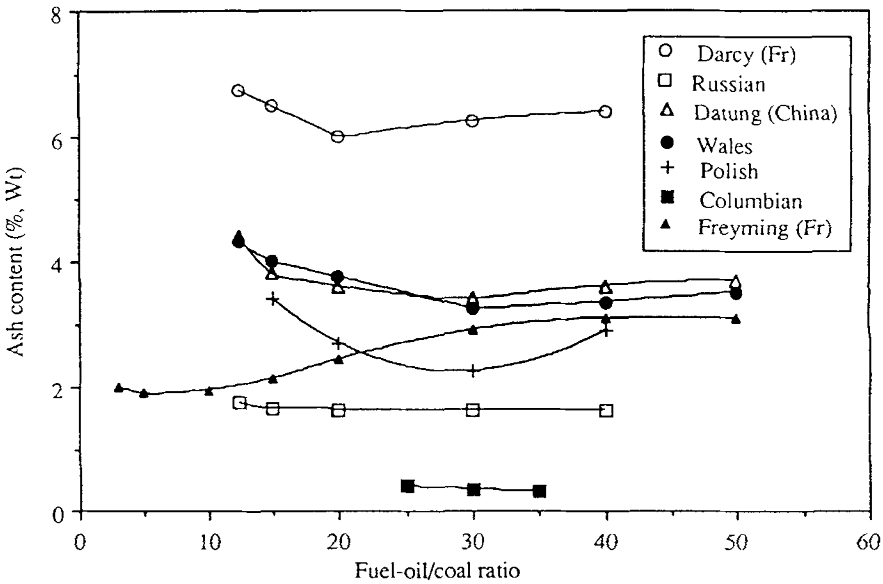

FIG. 3 Ash content as a function of the fuel oil/coal ratio.

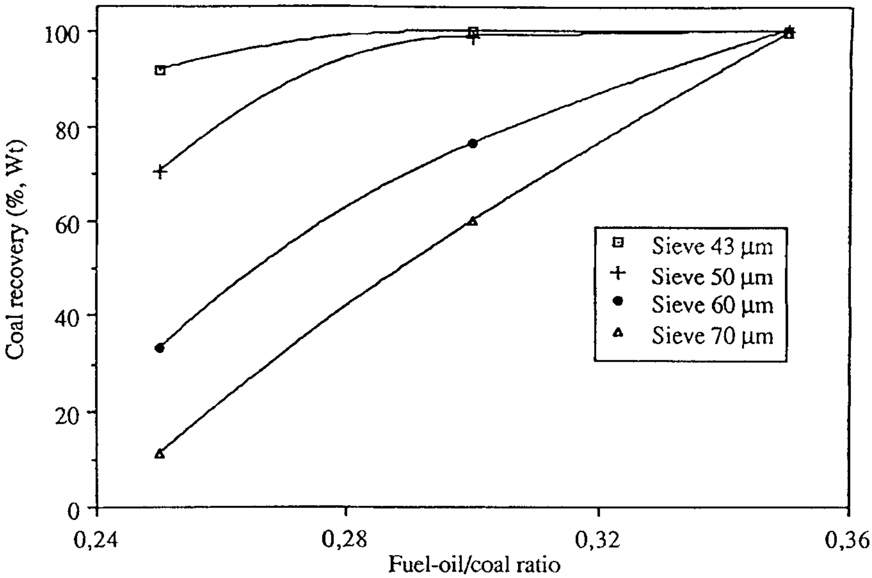

FIG. 4 Recovery of Columbian coal as a function of the fuel oil/coal ratio for different sieve diameters.

Effect of Nature of Coal

Coal agglomeration depends on the degree of hydrophobic character of coal particles. Low rank coals (12) or coals with an oxidized surface (13–15) have more affinity for water, and selective oil agglomeration becomes more difficult than for high rank coals. The hydrophobicity of various coals was found to decrease with decreasing coal rank, the fixed and total carbon content, and/or with increasing oxygen and hydroxyl content (12).

Table 3 shows the best results for different types of coal using light fuel oil as the agglomerating agent. It is observed that low rank coals, like German and French (Gardanne) lignite, cannot agglomerate. Ash reduction varies according to the type of coal, the initial ash content, and the nature of mineral matters included in coal. The cleaning efficiency of carbon matters varies from 36 to 75% for the studied coals. The best efficiency is obtained for high rank coals (Table 3), like Freyming and Columbian coal. Analysis of these samples shows an ash reduction of 65.5 and 75%, respectively. Anthracitic coals, the highest in rank, occupy a somewhat anomalous position in that their hydrophobicity is less than

TABLE 3
Ash Content in Feed Coal and in Agglomerated Product as a Function of Coal Nature

Type of coal (0 × 160 μm)	Rank classification	Initial ash content (%)	Ash content after cleaning (%)	Cleaning rate (%)
1. Freyming (Fr)	Bituminous	6.1	2.1	65.6
2. Darcy (Fr)	Bituminous	7	4.3	38.6
3. German coal	Bituminous	4	1.8	55
4. Upper Freeport (USA)	Bituminous	12	6.8	43.3
5. Columbian coal	Bituminous	1.6	0.4	75
6. Belgian	Anthracite	4	2.3	42.5
7. Prosacle (Fr)	Anthracite	7	4.4	37.1
8. Russian (Donetz)	Anthracite	4	2.6	35
9. Sophia Jacobi (Fr)	Anthracite	5	2.9	42
10. Chinese coal (Datung)	Antrhacite	5	3.2	36
11. Anthracite (Fr)	Anthracite	10	6.4	36
12. Polish coal		4.5	2.0	55.6
13. Wales		7.3	3.3	54.8
14. Graphite/copper		7	1.3	81.4
15. Lignite (Gardanne-Fr)	Lignite	9.2	—	—
16. Lignite (German)	Lignite	8.4	—	—
17. Tailings (Wendel-Fr)		27.5	2.1	92.4
18. Tailings (Freyming-Fr)		25	3	88
19. Petroleum coke		1.7	0.45	73.5

the higher rank bituminous coal (3). This can explain the less important agglomeration quality of these coals and, consequently, the lower cleaning efficiency as compared with bituminous coal.

Good purification is also obtained for a graphite/copper mixture (81.4%) and for coke of petroleum (73%). Very high cleaning efficiency has been obtained with tailings of Freyming and Wendel coal, 88 and 92.4%, respectively.

We have observed a linear relationship between the initial and the final ash content for high and medium coal ranks and for a particle fraction of − 160 μm (Fig. 5). Only the graphite/copper mixture and tailings of Freyming and Wendel present a better ash cleaning efficiency than the predicted one (Fig. 5).

Effect of Particle Size

Selective oil agglomeration is able to eliminate mineral matter which is liberated from carbon matter. The degree of mineral matter liberation increases with the intensity of coal grinding. The type and conditions of

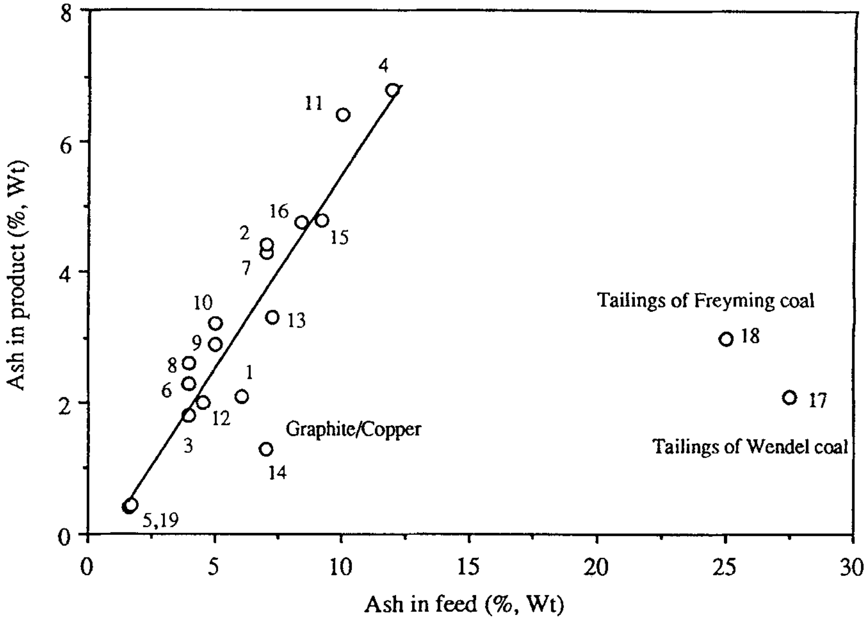

FIG. 5 Relation between feed and agglomerated product ash content for the coals studied. The numbers refer to the type of coal as listed in Table 3.

grinding can affect the hydrophobicity of coal (15). In this study, reduction of coal size was carried out with a wet grinder.

Figure 6 shows the ash reduction obtained for three types of coal and tailings of Wendel coal as a function of particle mean size. Note that maximum coal purification is obtained with maximum size reduction. The cost of grinding does not allow excessive particle size reduction, and a compromise is necessary between efficiency of ash reduction and grinding.

Recovery of coal is affected by particle size (Fig. 7). Recovery decreases with a decrease of particle mean diameter for a given sieve. To obtain good recovery of small particle size, a higher amount of fuel oil is necessary. Smaller particles need more oil in order to be wetted as well as more agitation time in order to obtain the same agglomerate size as bigger particles.

Effect of Temperature

Oil agglomeration can be influenced by temperature, when oil viscosity changes considerably with variation of temperature. Oil viscosity can af-

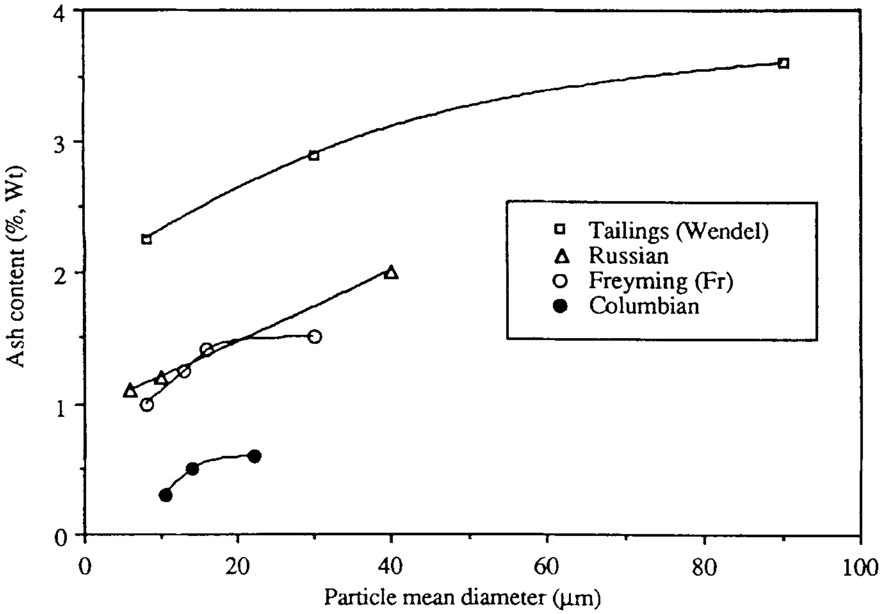

FIG. 6 Ash increase as a function of particle mean diameter.

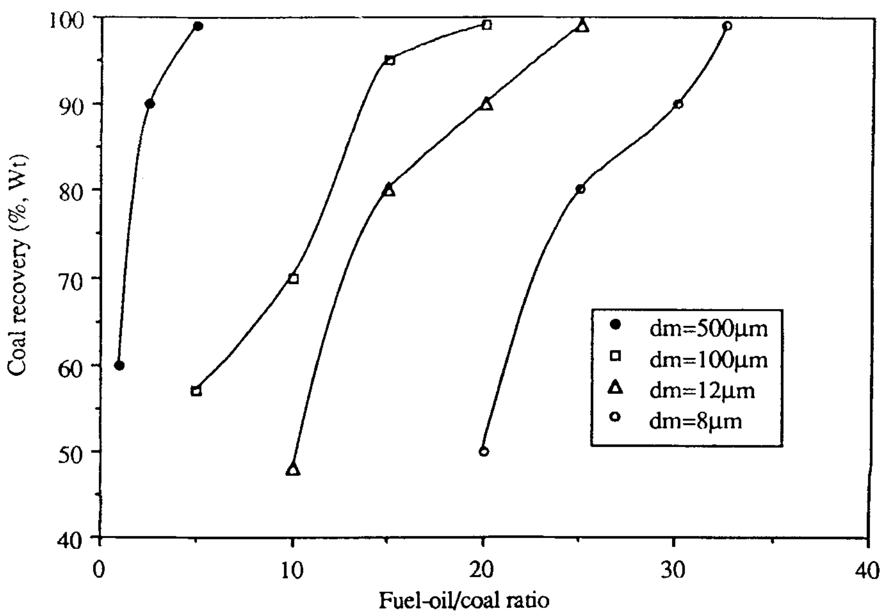

FIG. 7 Coal recovery as a function of fuel oil/Freyming coal ratio for different particle mean diameters (sieve diameter 160 µm).

fect agglomeration process, as it is shown above (Fig. 1). In the case of oil with low viscosity as light fuel oil (viscosity 3 cP), it is observed that temperature does not affect the process.

Effect of pH

Many authors have studied the effects of pH and ionic strength on coal recovery and the separation efficiency of mineral matter (16–18). These effects depend on the surface properties of particles. For example, it was found that the recovery of hydrophilic Illinois No. 6 coal with heptane decreased greatly as the pH was raised from 6 to 9 whereas the recovery of hydrophobic Upper Freeport coal (Pennsylvania, USA) decreased only slightly (18). However, after the surface of the Upper Freeport coal had been oxidized and rendered hydrophilic, the effect of pH on coal recovery was similar to that observed with Illinois No. 6 coal.

The effect of pH of Freyming coal in water suspension was studied by adding 0.1 M H_2SO_4 or NaOH. A maximum ash reduction (ash content 2.1%) occurs between pH 7.5 and 8. The change of pH leads to an improvement of about 25% in the deashing efficiency. However, according to Allen et al. (17), the effects of pH and ionic strength on agglomeration behavior are greater with a low oil dosage. The study of Freyming coal carried out for a 0.05 oil/coal ratio is considered to be a low oil dosage, and it explains the important variation in the deashing efficiency.

For the study of the other effects, the different types of coal were conditioned at the natural pH of suspensions, which generally use a greater oil dosage.

Effect of Concentration of Coal/Water Suspension

The concentration of coal in water is generally not a critical factor in oil agglomeration, according to Swanson et al. (19). However, it can affect the quality of coal cleaning, according to our results. A high concentration of coal does not give the free space necessary for mineral matter to be separated from coal particles. Some impurities are then imprisoned among the coal particles during agglomeration, and thus increase the ash included in coal (Fig. 8).

Increased dilution would require prolonged mixing to ensure that contacts occur. Very low concentrations of coal are undesirable because to the large volume of water which must be handled. A mass concentration of more or less 10% of coal in water has given good results and was adopted for this part of our experiments. This concentration is higher than that in the flotation process for coal cleaning (5, 20).

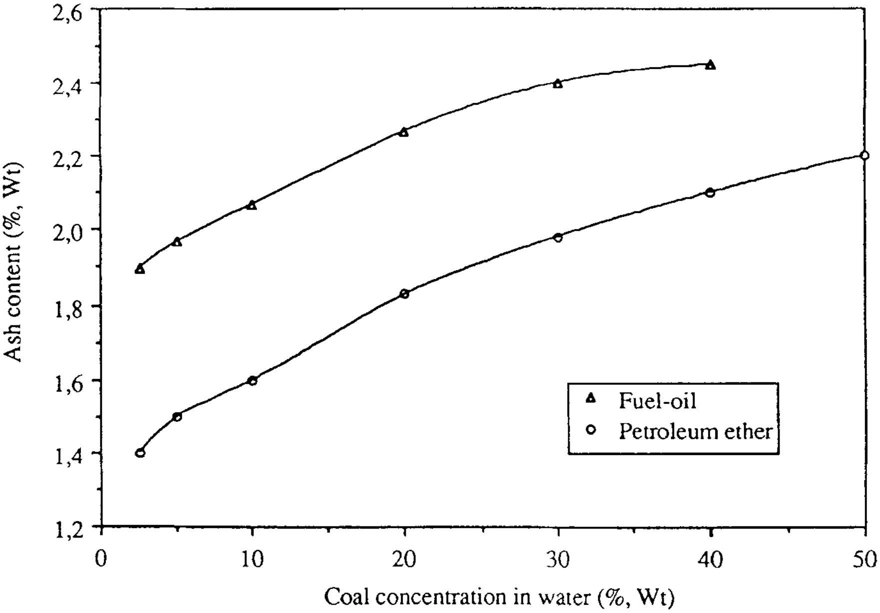

FIG. 8 Effect of coal (Freyming) concentration on ash content for fuel oil and petroleum ether as oils.

Effect of Conditioning of Coal/Water Suspension

Low rank coals and coals that are weathered or oxidized may require a reagent conditioner to render the particles hydrophobic. Venkatardi et al. (15) proposed traces of sodium oleate in order to improve the separation of pyrite and weakly hydrophobic coals. The use of salt solutions in the oil agglomeration process can reduce oil consumption and improve the separation of mineral matter (21).

In this study, aliphatic alcohols have been tested as reagents to improve the agglomeration process. Two low rank coals, the lignite of Gardanne (ash content 9.2%) and a German lignite (ash content 8.4%) were tested. Light fuel oil utilization does not provoke good particle agglomeration for these types of coal, as is shown in Table 3.

Alcohol was added to a coal/water suspension. An agitation period was necessary for contact among particles and alcohol. Then light fuel oil was added and the experiment was carried out according to the conditions already described.

The results obtained are shown in Table 4. It is noted that only alcohols with at least seven carbons favor agglomeration for the two types of lig-

TABLE 4
Ash Content of German and French Lignite as a Function of Alcohol Carbon Number. Concentration of Alcohol: 3×10^{-4} mol/g Coal; Coal/Water Ratio: 0.05; Fuel/Coal Ratio: 0.39; Wetting Period: 1 min; Agglomeration Period: 15 s

Lignite	Mean diameter (μm)	State	Ash content % (w/w) by alcohol carbon number							
			1	2	4	6	7	8	10	12
German	10	Initial %	8.4	8.4	8.4	8.4	8.4	8.4	8.4	
		Purified %	—	—	—	—	4.75	4.82	4.95	
		Rejected %	—	—	—	—	43.4	42.6	41.1	
French	6	Initial %	9.2	9.2	9.2	9.2	9.2	9.2	9.2	
		Purified %	—	—	—	—	4.8	4.8	5	
		Rejected %	—	—	—	—	47.8	47.8	45.7	
	12	Initial %	9.2	9.2	9.2	9.2	9.2	9.2	9.2	9.2
		Purified %	—	—	—	—	5.6	5.7	6.0	6.0
		Rejected %	—	—	—	—	39.1	38.0	34.8	34.8

nite. Optimum ash reductions (43.4% for German lignite and 47.8% for French lignite) were obtained with the addition of heptanol. Also, particle size reduction seems to improve these results.

Effect of Agitation Intensity and Agitation Time

Agitation on agglomeration was carried out with a high-speed agitator equipped with a shear impeller mixer. This type of agitation is often used for oil agglomeration (22). It allows oil to disperse well into a coal/water suspension and it make contact of oil with coal particles easier.

The growth of agglomerates generally increases with agglomeration time (2). For each type of coal an optimum time is required in order to obtain good agglomeration (ash reduction, coal recovery). Ash reduction increases with agitation time to an optimum value (Fig. 9). A prolonged time of agglomeration substantially increases the agglomerate size and favors the imprisonment of impurities into agglomerates. The optimum agglomeration time varies between about 10 and 60 seconds for the coals studied.

A minimum agglomeration time is necessary to obtain the maximum recovery of coal. This time depends on the nature of the coal and the oil/coal ratio. An example is given for Freyming coal (Fig. 10). Agglomeration time varies between 5 and 10 seconds according to the fuel oil/coal ratio. The decline after a maximum recovery may be attributed to the formation of a weak coal–oil amalgam passing through the collecting sieve screen with the addition of excessive amounts of oil (5, 15).

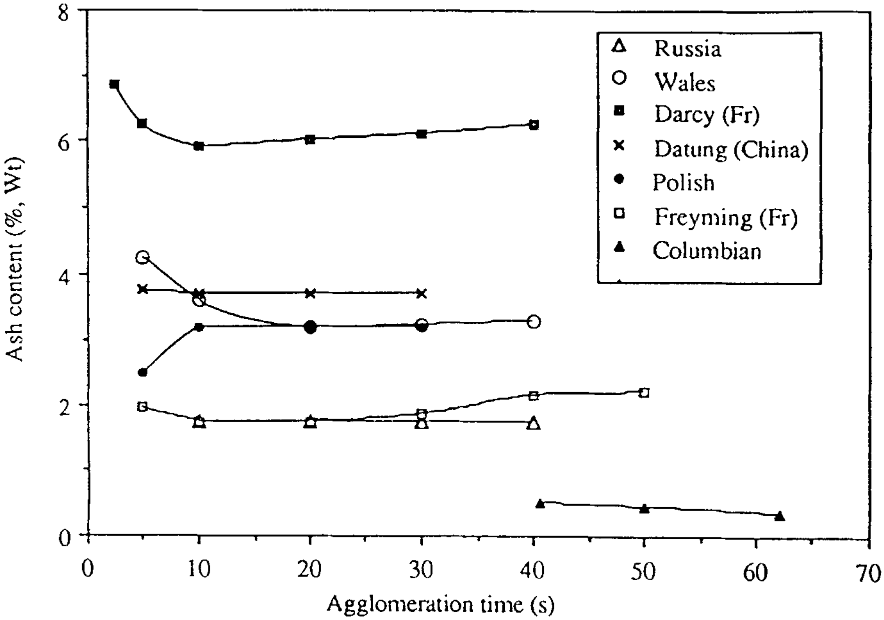

FIG. 9 Variation of ash content with agglomeration time for different coals.

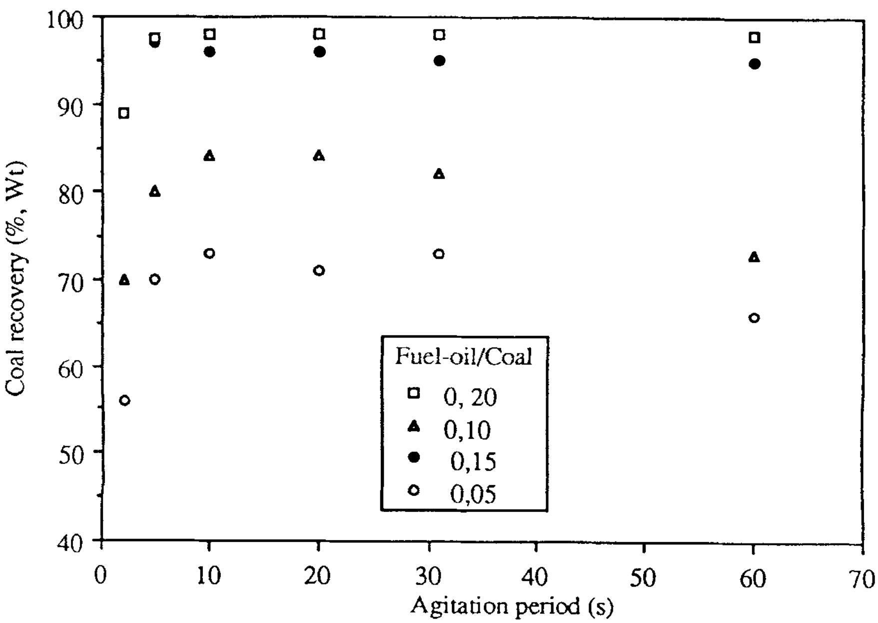

FIG. 10 Recovery of Freyming coal as a function of agitation period for different fuel oil/coal ratios.

Agitation intensity is also important for good agglomeration. For a given agglomeration time the recovery of Freyming coal increases with the stirring speed, which favors contact between oil and coal particles and allows a higher growth of agglomeration. A minimum speed of 2500 rpm is required for the maximum recovery of coal (Fig. 11).

Kinetics of Coal-Oil Agglomeration

Many studies (2, 22–25) have been carried out in order to determine the kinetics and mechanism of the batch agglomeration process and to predict the size distribution of the agglomerates. Rao and Vanangamudi (23, 24) found that the growth of agglomerates carried out with Dugda-I and Patherdith coal samples in a batch process follows second-order kinetics and is given by

$$\frac{t}{d_{50}} = \frac{1}{k_2 d_{50\infty}^2} + \frac{t}{d_{50\infty}} \quad (1)$$

where d_{50} is the mean size diameter, $d_{50\infty}$ is the maximum d_{50} that can be attained after a prolonged period of agglomeration (μm), t is the agglomeration period (s), and k_2 is the second-order rate constant ($s^{-1} \cdot \mu m^{-1}$).

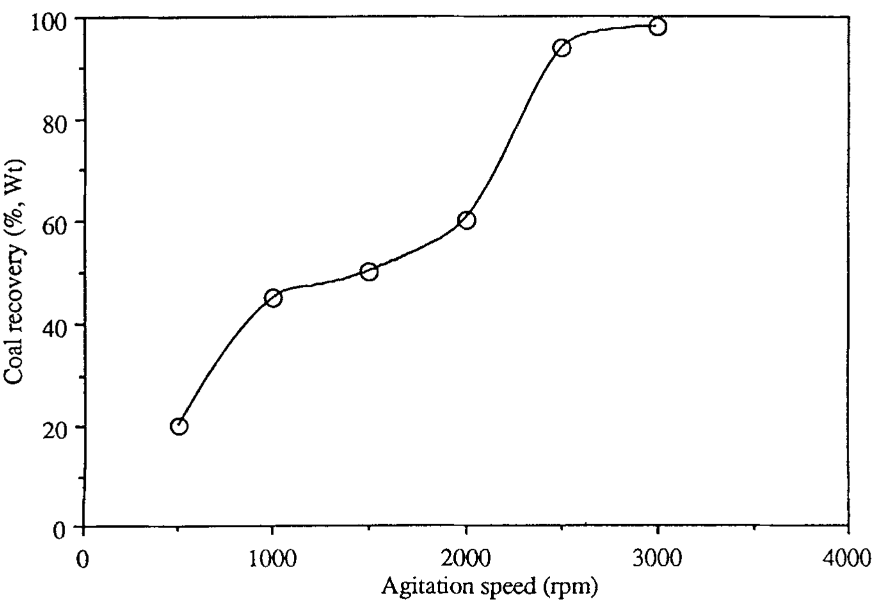

FIG. 11 Influence of agitation speed on recovery of Freyming coal.

The same relationship has been confirmed in our laboratory in a continuous agglomeration process using Columbian coal (2). Knowledge of the constants k_2 and $d_{50\infty}$ therefore allows the growth of agglomerates as a function of agglomeration time and the mean diameter of coal particles to be predicted.

Reduction of Moisture in Agglomerates

Another property of coal-oil agglomeration is partial coal dewatering with the removal of the adsorbed water into agglomerates. This water is difficult to remove by mechanical dewatering. Oil agglomeration allows the water to be replaced with the used oil. This reduction depends on the amount of oil. A high fuel/coal ratio increases the compactibility of agglomerates, facilitates water removal, and fills the spaces between particles with oil (Fig. 12). High agglomeration time favors contact between coal and oil and consequently aids moisture reduction. An increase in coal particle size contributes to improved humidity reduction because of the decrease of specific surface and particle porosity which retain water.

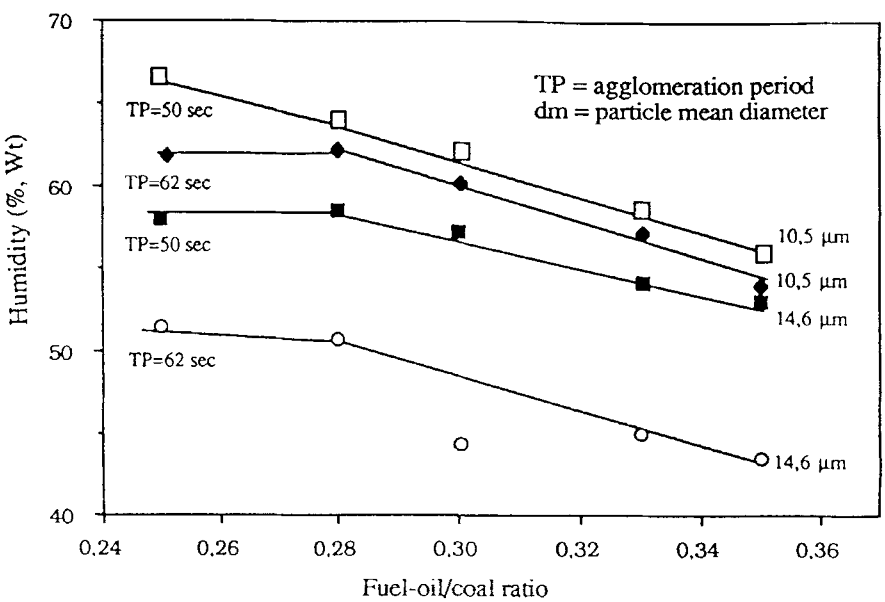

FIG. 12 Effect of fuel oil/Columbian coal ratio on moisture reduction for different agglomeration periods and particle mean diameters.

A linear relationship has been observed by some authors (5) between moisture and $1/d$ (d is the agglomerate size) when discrete coal agglomerates are formed ($1/d \leq 10\ mm^{-1}$). A linear relationship was also obtained for flocs ($1/d \geq 10\ mm^{-1}$) of Columbian coal (Fig. 13). More tests are necessary to confirm this observation for diverse coals.

Selectivity of Ash Rejection Elements

Quantitative ash chemical analysis of some studied coals is shown in Table 5. An important reduction of all ash elements after the agglomeration process is observed. A lower reduction is observed for Chinese coal. The coal particle size of Chinese coal explains its lower efficiency for oil agglomeration. In fact, the liberation of mineral materials from carbon materials increases when the intensity of coal grinding increases.

The reduction of total sulfur is important. Pyritic sulfur is generally difficult to reduce because of its similarity in hydrophobicity with carbon materials. Under the conditions we used for selective oil agglomeration, pyritic sulfur shows a good reduction. The results obtained also show a reduction of alkaline oxides (K_2O, Na_2O, CaO) which cause serious corrosion in boilers and turbines.

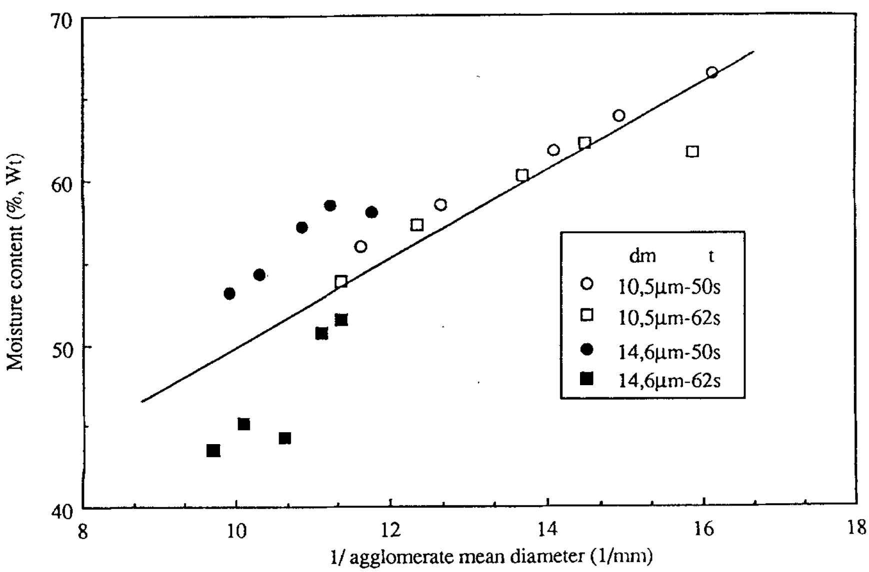

FIG. 13 Moisture in agglomerates as a function of agglomerate mean diameter for different coal mean diameters and agglomeration periods.

TABLE 5
Coal Ash Analysis

	% (w/w)	Ash (%)	SiO_2 (%)	AlO_3 (%)	Fe_2O_3 (%)	TiO_2 (%)	CaO (%)	CaMgO (%)	K_2O (%)	Na_2O (%)	SO_3 (%)	P_2O_5 (%)	Total sulfur	Pyritic sulfur
Freyming coal, 0 × 40 μm	Initial	6.1	41.7	30.9	12.5		2.3	4	4.9	0.5	3.3		0.74	0.17
	Purified	1	22.6	28.5	32.4		6.6	2.8	2.1	0.3	4.5		1.06	0.10
	Rejected	83.6	91.1	84.9	57.5		53	88.5	93	90.2	77.6		16.5	90.4
Columbia coal, 0 × 160 μm	Initial	1.6	51	24.7	14.1	2.8	2.5	1.3	1.2	1.8	0.6		0.49	0.01
	Purified	0.4	31.6	22.3	24	5.8	9.8	1.7	1.9	2.2	0.7		0.3	0.01
	Rejected	75	84.5	77.4	57.4	48.2	2	67.3	60.4	69.4	70.8		84.6	75
Chinese coal, 0 × 500 μm	Initial	18	44.2	42.3	3.8	1.8	3.8	0.3	0.4	0.1	2.5	0.8		
	Purified	10.8	45.4	41.9	4	2.1	3.3	0.5	0.5	0.1	1.2	1		
	Rejected	40	38.2	40.6	36.8	30	47.9	0	25	40	71.2	25		
Russian coal, 0 × 130 μm	Initial	4.9	34.1	22.2	30.5		4.1	1.9	1.4	1.4	4.1		1.16	0.4
	Purified	2	37.4	25.2	23.4		3.5	1.3	1.7	3	4.2		0.81	0.16
	Rejected	59.2	55.2	53.6	68.7		65.2	72	50.4	12.5	58.2		71.5	83.7
Wendel tailings, 0 × 40 μm	Initial	27.5	50.8	25.1	12.5		0.6	4.3	4.8	0.4	1.3		1.01	0.47
	Purified	2.1	40	27.7	20.5		2.4	2.2	4.2	0.4	2.2		0.77	0.17
	Rejected	92.4	94	91.5	87.5		69.5	96.1	93.3	92.4	87		94.2	97.2
Petroleum coke, 0 × 150 μm	Initial	1.7	12.5	3.8	53.2	0.3	6.4	1.1	0.6	1.1	1.8	0.5	5.42	0.01
	Purified	0.45	12.7	5	45.6	0.5	8	1.5	0.6	1	0.5	0.7	5.16	0.01
	Rejected	73.5	73.1	72.9	77.3	55.9	66.9	63.9	73.5	75.9	92.6	63	74.8	73.5

CONCLUSION

Selective oil agglomeration has shown good performance as a physical method to purify different types of coals or tailings.

Freyming and Columbian coals petroleum coke, tailings (Wendel, Freyming), and a graphite/copper mixture show good deashing efficiency (better than 65%). The other coals of high or medium rank present a lower deashing efficiency (between 36 and 55%). Alcohols with at least seven carbons can be used as effective reagents to modify the surface properties of coal when there are insufficient hydrophilic particles. All ash elements, and especially alkaline oxides as well as total and pyritic sulfur, are selectively rejected at a high level.

Improvements in ash reduction and coal recovery efficiencies are possible through an optimization of the parameters studied. An oil viscosity ranging between 0.6 to 10 cP is the optimal range. For high and medium coal ranks, a linear relationship was obtained between the initial and final ash content obtained in coal. The mineral materials liberated depend principally on the degree of coal grinding. The optimal fuel oil/coal ratio for the coals studied is generally between 0.20 and 0.30 in order to obtain minimal ash and maximal coal recovery. Agitation time/intensity should be adapted for each type of coal in order to obtain the oprtimum agglomeration efficiency. The prediction of agglomerate moisture may be possible from agglomerate mean size. Second-order kinetics can be obtained for a continuous coal–oil agglomeration process.

SYMBOLS

d	diameter of particles or sieve (μm)
d_m	mean diameter (μm)
d_{50}	median diameter (μm)
$d_{50\infty}$	the maximum diameter d_{50} that can be attained after a prolonged agglomeration period (μm)
F/C	mass ratio of fuel/coal
k_2	the second-order rate constant ($s^{-1} \cdot \mu m^{-1}$)
t	agglomeration period (s)

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